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REBUILDING THE FIVE MEGAJOULE HOMOPOLAR MACHINE AT THE UNIVERSITY OF TEXAS

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Abstract

The role of the 5 MJ homopolar machine at the Center for Electromechanics has changed from that of a pulsed power supply experiment to that of a power supply for various experiments. Because of this change in duty, it was necessary to modify the machine to allow more efficient operation and easier connection of the machine to the load.

The experimental bearings which were on the machine were replaced with bearings of a more conventional design. These bearings exhibit a higher stiffness and lower loss than the original bearings, making the machine more reliable and reducing motoring time.

The surface of the poles were faced to make the applied field more uniform over the face of the rotor. This reduced the magnetic moment on the rotor and reduced the side forces on the rotor during discharge.

The busbars were rebuilt to lower the resistance of the output circuit and to allow quicker change of experiments. The latching mechanism of the closing switch was rebuilt for better reliability and a damper was added to lower the mechanical shock on the switch during operation.

Introduction

The 5 MJ slow discharge homopolar generator (SDHG) (Figure 1) was built in 1974 by The University of Texas Center for Electromechanics to demonstrate the feasibility of inertial energy storage using homopolar conversion. It has been discharged hundreds of times and has proven so reliable that it is still in daily use as a pulsed power supply for other laboratory experiments. Its 730 kg steel rotor is 61 cm in diameter, 28 cm thick, and operates in a 1.6 tesla axial magnetic field. Originally designed to produce 165 kA, the machine's low internal impedance (resulting from an improved brush mechanism) permits the generator to produce up to 560 kA, stopping the rotor from half speed (2800 rpm) in 0.7 seconds.

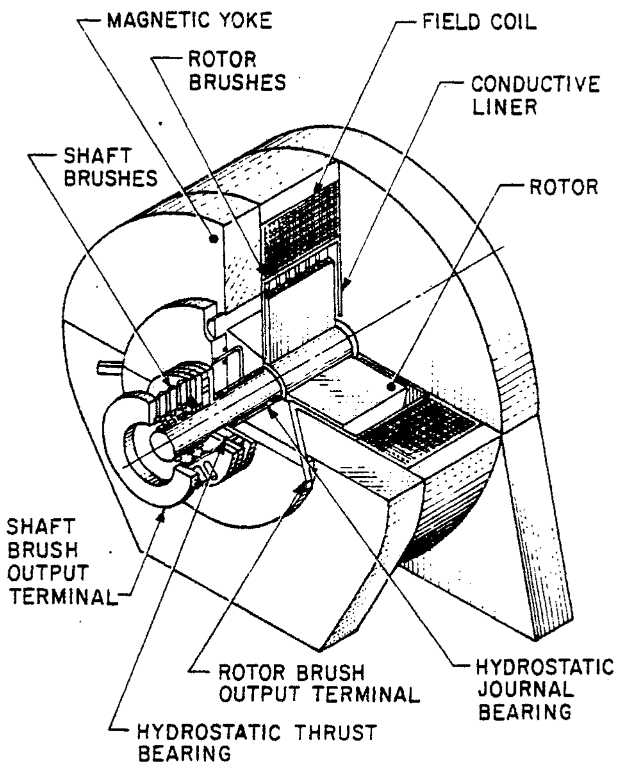

Figure 1: Schematic of 5 MJ SDHG.

After repeated discharges in the short circuit mode proved the basic reliability of the 5 MJ machine, it

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was connected to various loads in order to study such machine parameters as voltage, current, pulse rise time and discharge time. Three major series of laboratory experiments have been conducted that involve operational testing of the machine as a pulsed power supply.

1) Discharging into the fast discharge experiment (FDX) field coil (inductive store) to obtain maximum current in the coil.[1]

2) Discharging into the FDX field coil (inductive store) while controlling the shape of the current pulse by controlling the field excitation of the 5 MJ machine.

3) Pulsed resistance welding of 2" mild steel pipe.[2]

Reason for Rebuild

After completing these experiments, misalignment and out-of-roundness of the experimental hydrostatic bearings installed two and one-half years before resulted in an inability of the 5 MJ homopolar machine to be motored to speed with full field. A 4" stainless steel pipe resistance welding program would soon require many high level discharges. Therefore, to address the bearing problem and observe the internal condition of the generator after some two years of operational testing, the decision was made to redesign the bearings, disassemble the machine and upgrade the overall performance. Attention was paid to making the machine as reliable as possible, reflecting the change from its previous experimental status.

Bearings

Homopolar machines have stringent bearing requirements. A large diameter rotor shaft is required for a disc type homopolar generator, since the shaft is used as a conductor and the larger diameter lowers the resistance. (For the 5 MJ machine, resistance of its five-inch shaft is about one-third of the total machine resistance.) Because the shaft is larger in diameter than would normally be used on a rotor of the same size and weight, the resulting bearing interface surface speed is much higher than in conventional rotating machines.

Desirable bearing design features include:

1) Very low losses (reduce motoring time).

2) Full stiffness at zero speeds. (Bearing loads in homopolar generators are as large at zero speed as at full speed.)

3) Electrical insulation (to prevent arcing during a discharge and eliminate circulating currents in the bearings).

Of the three types of bearings, rolling element (unacceptable due to high magnetic fields in the bearing location), hydrodynamic (unacceptable because of zero load capacity at zero speed) and hydrostatic, only the hydrostatic bearing can be designed to achieve all of these goals.

Two configurations of hydrostatic bearings had been tested before the rebuild. Originally, a set of stainless steel bearings, which were not insulated from the bearing housing, were used. Although they functioned satisfactorily at the original design currents, during a high-level discharge the shaft arced to the bearings, causing pitting of the shaft and bearings. Bearings made of G-9 melamine (a nonconductive, fiberglass-reinforced material) replaced the stainless steel bearings. These bearings functioned for over two years, but thermal creep ultimately resulted in bearing misalignment and loss of stiffness which necessitated that the machine be run at reduced field levels. Friction and I^2R losses would cause the shaft to expand, but the melamine bearings (which have a very low modulus) were prevented from expanding because they were confined by the stainless steel bearing housing. This resulted in reduced clearance in the bearing which increased shaft heating, further reducing bearing clearance and resulting in rubbing between the shaft and bearing. In addition, the bearing housings were misaligned and out-of-round, causing the bearings to be oval-shaped and misaligned.

The third configuration of hydrostatic bearings (Figure 2) which are currently in the machine, addressed these and other problems. A conventional bronze bearing insert with a hardened steel shaft was designed. The insert was insulated from a shrunk on steel housing with a layer of flame sprayed aluminum oxide ceramic. The bearing has six pockets and is orifice compensated. By tapering the journal bearing as shown in Figure 3 an adjustable clearance was obtained. Table 1 shows the bearing characteristics.

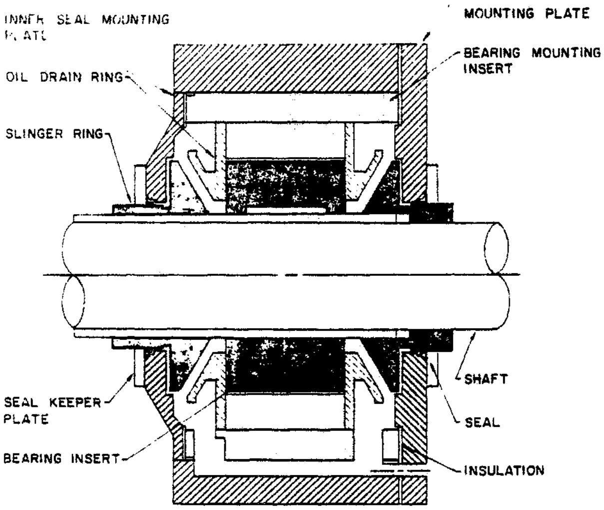

Figure 2: Hydrostatic Journal Bearing

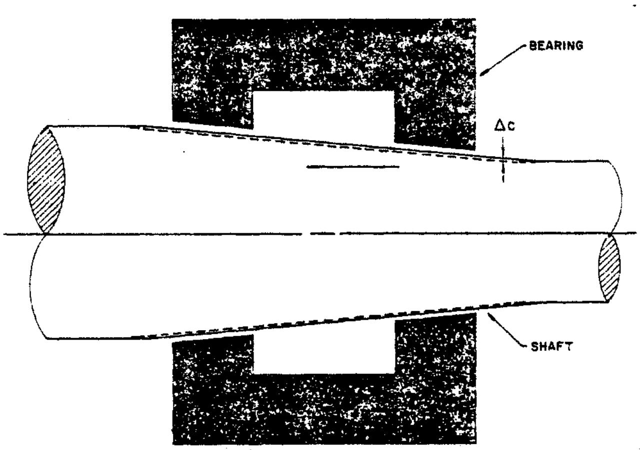

Figure 3: Tapered Shaft and Bearing

To correct the misalignment and out-of-roundness of the bearing housings, a boring bar was built which would line bore both housings while they were installed in the 5 MJ yoke. In addition, a facing mechanism was attached to the boring bar, to face the poles of the machine perpendicular to the new bearing housing bore. This significantly reduced the tilt forces on the rotor caused by misalignment in the magnetic field.

One of the major problems with high-speed hydrostati bearings involves the design of a sump system that will remove the large oil flow and prevent leakage at the high speed seal interface. The current design provides very large sumps which operate below atmospheric pressure. This allows the seals to leak air into the sump rather than leaking oil out.

Machine Disassembly

Careful inspection of the disassembled machine revealed that the rotor and all brushes were in good condition. As anticipated, the bearing showed signs of rubbing and some pitting had occurred on the shaft under the shaft brushes. The making switch was in good condition except for the external latching mechanism that had become loose and misaligned. Overall, the disassembly resulted in no surprises and the machine was sound.

Making Switch

Upgrading of the machine included disassembly and rework of the generator making switch (Figure 4). All electrical contacts and conductors were in good condition and were reassembled without rework. Rework of the switch included:

1) Pins at the pivot points on the latch mechanism showed excessive wear and damage from impact loading, resulting in a lack of reliability of the hold-open latch. The pins were increased in size to reduce unit loading, assembly tolerances were tightened, a new damper was added to reduce the impact of the pneumatic cylinder and the latch was reground and repositioned

Table 1

Hydrostatic Bearing Characteristics

Oil Viscosity cp (Reyn)	Radial Clearance mm (in.)	Load* N(lb)	Stiffness N/m (lb/in.)	Flow Liter/min (gpm)	Total Loss kW (hp)
62.1 (9×10^{-6})	0.102 (0.004)	3.47×10^4 (7800)	1.70×10^8 (0.972×10^6)	15.7 (4.16)	20.4 (27.4)
13.8 (2×10^{-6})	0.038 (0.0015)	1.24×10^4 (2781)	8.91×10^8 (5.09×10^6)	8.25 (2.18)	9.10 (12.2)

*Load: Given for a minimum film thickness of 0.025 mm (0.001 in.).

2) The original electromagnetic solenoid, which initiates switch actuation, was a surplus unit and was replaced with a commercial unit.

3) Redesign of the latch adjusting mechanism now allows adjustment to be made with the solenoid in place.

Busbars

Before the rebuild, the output busbars and making switch had to be removed before the generator could be disassembled (Figure 5). The new design rotated the 2.86 cm by 30.5 cm aluminum discharge busbars 90° so that they face the FDX generator. Lifting eyes were attached to the top of the yoke providing quick access to the machines interior for inspection and repair.

By rotating the FDX field coil 90° toward the 5 MJ SDHG it was possible to attach the coil directly into the switch output. This made the low impedance copper busbars used previously to connect FDX to the 5 MJ generator free for quick installation of other experiments. The new busbar arrangement lowered both the resistance and inductance of the output circuit.

Conclusion

Many high current discharges have been accomplished

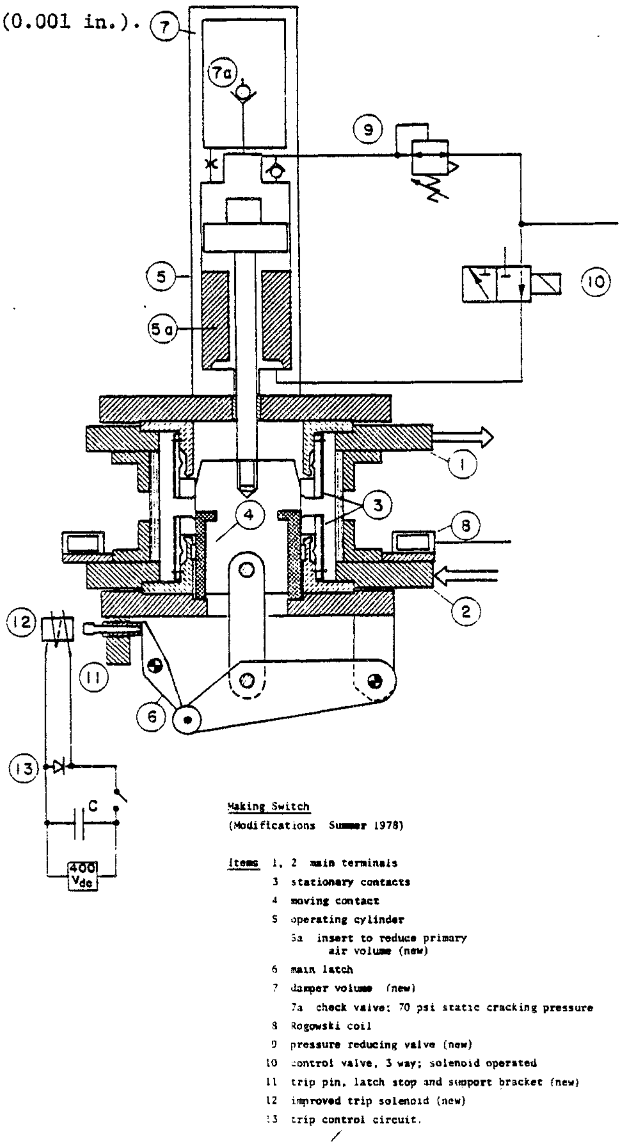

Figure 4: Making Switch

since the rebuild (Table 2). The machine has proven to be reliable and maintenance free. In the near future, welding and heating experiments will continue. Other possible experiments include FDX, pulse compression and some rail gun experiments. The 5 MJ SDHG is no longer an experiment; it is now a reliable pulsed power supply for high energy experiments.

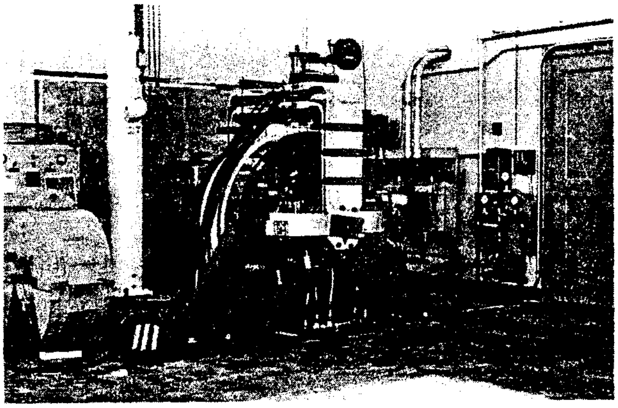

Figure 5: Old Busbar

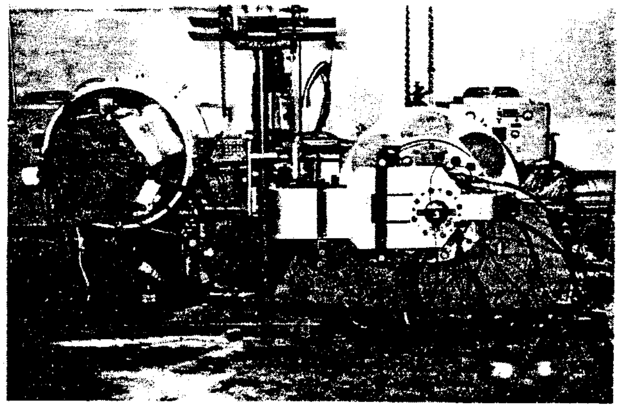

Figure 5: New Busbar

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2. G. B. Grant, W. M. Featherston, R. E. Keith, W. F. Weldon, H. G. Rylander, H. H. Woodson, "Homopolar Pulse Resistance Welding, A New Welding Process - based on the unique electrical characteristics of pulsed homopolar generators," American Welding Society, 60th Annual Meeting, Detroit, Michigan, April 2-6, 1979.

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Table 2: 5 MJ SDHG Discharge Levels

	0-50 kA	50-100 kA	100-150 kA	150-200 kA	200-250 kA	250-300 kA	300-350 kA	560 kA
Before Rebuild	54	98	20	20		2	1	1
After Rebuild	1	26	7	2	0	17	28	